Dynamic Systems Lab
Center for Nonlinear Dynamics & Control
Villanova University
7th Annual AUVSI RoboBoat Competition
July 8, 2014

ABSTRACT

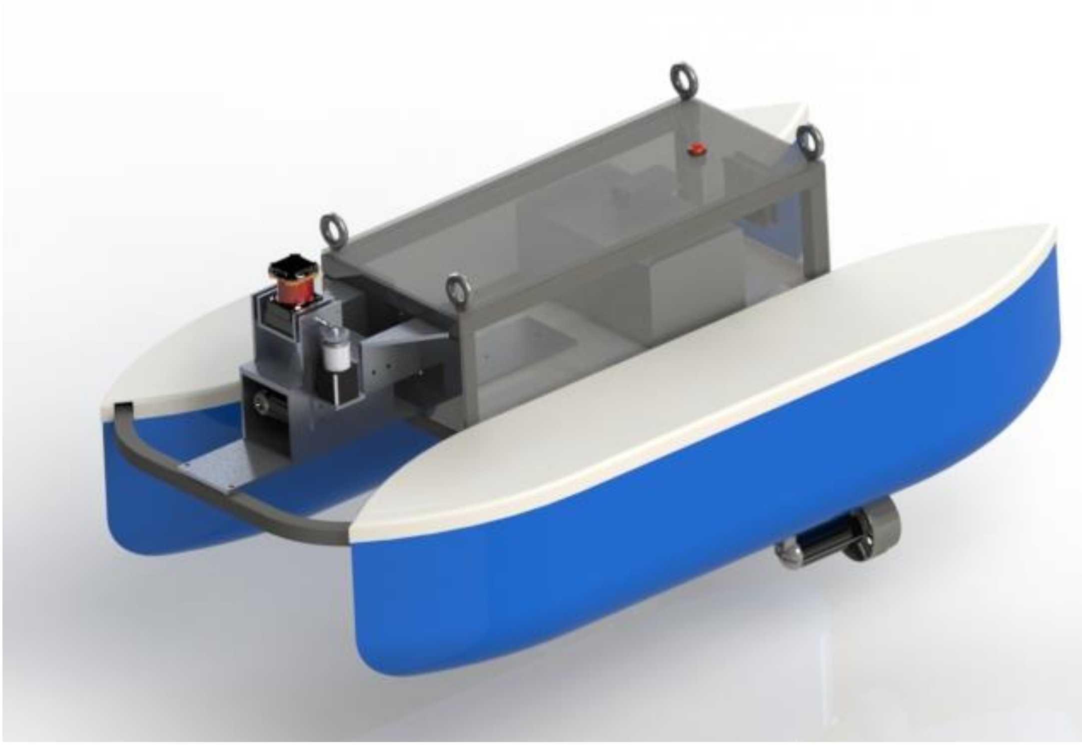

Figure 1: CAD Rendering of SeaCat

SeaCat (Figure 1) is a twin-hulled catamaran-style autonomous surface vehicle designed and built from the ground up by students from Villanova University. Making its third appearance this year at the 7th Annual AUVSI RoboBoat Competition, SeaCat has proved to be a stable and adaptable platform upon which modifications can be made to meet the challenging requirements of this year's tasks. The tasks this year include underwater color sequence detection, obstacle field navigation, underwater acoustic location, and vision based autonomous docking.

This year's work was focused on implementing major improvements in both the hardware and software aspects of SeaCat in order to improve the overall robustness of all aspects of the system. This includes an updated sensor suite with the addition of a LIDAR/Video sensor fusion system, hydrophones, and a new IMU, the development of an innovative fast Simultaneous Localization and Mapping (SLAM) algorithm for path planning, the implementation of a novel probabilistic model through Bayesian filtering for more accurate color recognition, and the development of a template matching algorithm for symbol detection and recognition.

INTRODUCTION

Autonomy is a rapidly growing interdisciplinary field focused on designing systems and vehicles that can operate independent of human input. The high interest is due to the fact that it holds great promise in advancing countless industries in both military and civilian sectors as the technology matures.

The AUVSI RoboBoat Competition was conceived in order to promote research in this field and to encourage the discovery of real-world applications of autonomous systems in the context of surface vehicles. SeaCat is Villanova University's entry into this competition.

PHYSICAL DESIGN

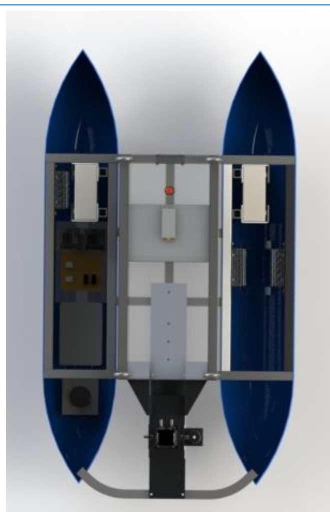

Figure 2: Top View of SeaCat with Location of Internal Components

SeaCat is a twin-hulled catamaran-style vessel. The two pontoon hulls are made from custom hand-laid fiberglass featuring a removable top cover which permits the placement of components within the pontoons themselves. This results in a low center of mass which allows for the effective decoupling of yaw and roll motions of the boat. In combination, the twin hulled structure and the low center of mass provide increased stability to the platform, which is a great improvement over single hulled designs where the coupling of yaw and roll motions severely limit control precision and independence for the various degrees of freedom. The use of corrosion resistant PVC tubing and Plexiglass for the construction of the frame instead of aluminum also significantly reduced the weight of the vessel

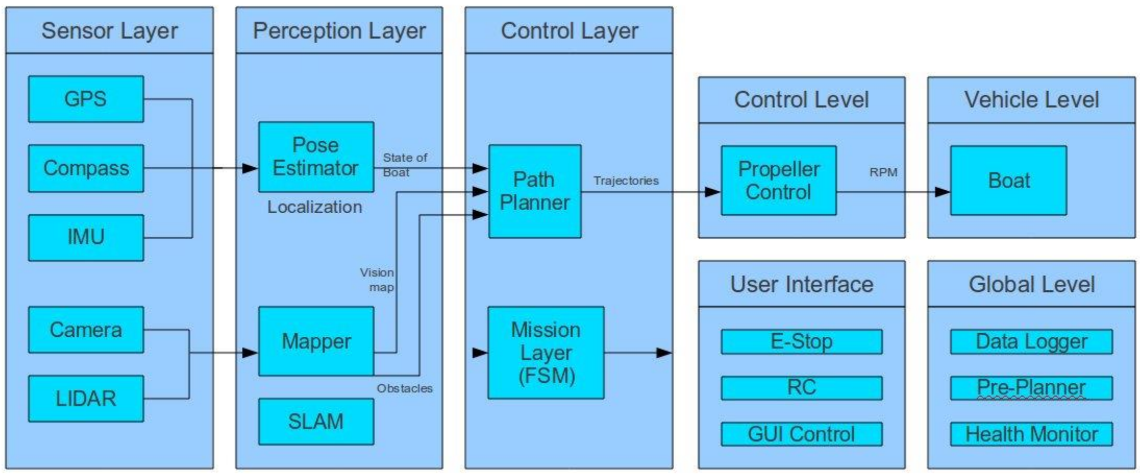

Figure 3: Flow Chart of SeaCat Logic

HARDWARE

Speedgoat

The onboard computer is a Speedgoat real-time target machine. The advantage of a real-time machine over conventional computers is its ability to sample sensor data and output decisions all in real time as opposed to building up a queue of tasks. This is crucial to autonomous systems which need to make rapid decisions based on the most recent information available.

LIDAR/Video Fusion

Planar LIDAR systems (i.e., a LIDAR that collects range information from one plane in the scene being measured) are very popular in robotic vision applications. It is common to extend these sensors to 3D by adding secondary (and sometimes tertiary) rotations to the sensor.

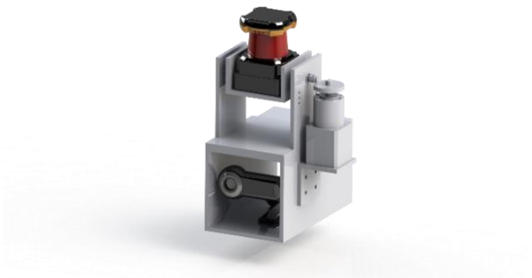

Figure 4: LIDAR/Video Fusion Assembly

Typically, these gimbaled LIDAR systems, as seen in Figure 4, utilize raster scan patterns, where scene information is gathered one plane at a time, with motion of the gimbal between scans or at a relatively slow rate. This process can be very time intensive depending on the desired resolution and range. This forces a compromise between sensor speed and resolution. Our innovative solution with a custom scanning procedure seeks to mitigate the effects of this compromise.

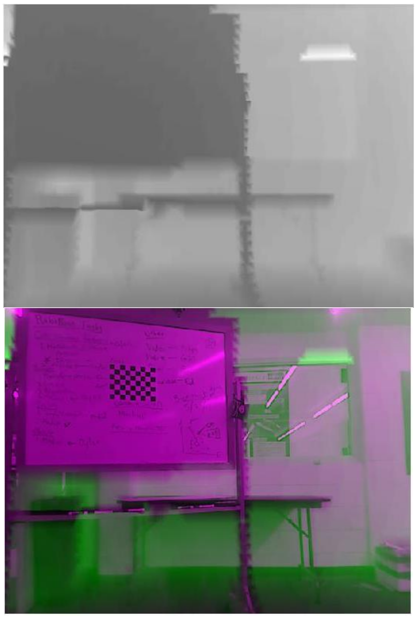

Figure 5: (Upper) Depth Map from LIDAR, (Lower) LIDAR and Video Fused Image

In order to accomplish a proper fusion between the depth information of a LIDAR unit and the color information of a camera as seen in Figure 3, it is critical to determine the relation between these two. To do this, the intrinsic properties of the video camera have been analyzed in order to understand how spatial information is interpreted in the image frame of the camera (this camera model includes characterizing focal length and lens distortion). At the same time, the scan data from the LIDAR is read in terms of ranges at different scanning and gimbal angles. This is first converted to 3D Cartesian coordinates, with the origin at the center of the axis of rotation of the gimbal. They are then transformed relative to the video camera, and the camera model described above is used to interpret the points in the image frame, which ultimately forms a depth image as illustrated by the upper image of Figure 5. An algorithm is employed to overlay this on the corresponding camera image to create the lower composite image.

Hydrophones

To complete the acoustic beacon positioning task, SeaCat has been fitted with two Teledyne Reson TC4013 hydrophones, one attached to the bottom of each pontoon. The hydrophones' outputs are attached to an amplifying circuit which holds their peak values for each ping. These peak values are read by an Arduino Due, which calculates the difference between the two signals.

Because sound intensity decreases proportionally to the inverse of the square of the distance from a single-point acoustic source, for positioning analysis, we can use a simple inverse square law between the intensities and the distances from the hydrophones to the point source. Knowing the distance between the two hydrophones, the approximate location of the acoustic source can be estimated. Because of how the hydrophones are mounted on the boat, when the boat is oriented towards the pinger the hydrophones will be equidistant from the acoustic source and will record the same sound intensity. On the other hand, when the boat is oriented at 90° from the pinger, the hydrophones will be at their largest relative distance from the acoustic source and will record the largest difference in sound intensity. The Arduino will record these differences in perceived intensities, estimate distances to the acoustic source, and calculate running averages in order to create an increasingly accurate estimate of which buoy is attached to the active pinger.

SOFTWARE

Most of the software written for SeaCat is created using Simulink models in MATLAB & Simulink. These models are compiled and built into executables through xPC Target, the MATLAB real-time software environment, and run by the Speedgoat target machine. Supplemental computing and subroutines are off loaded on to separate computing platforms. This not only allows for distributed computing among various independent processors, but, more importantly, it enables a parallel development cycle where each task of the competition can be developed as a separate module which is then integrated into the overarching structure through either serial communication or the Lightweight Communications and Marshaling (LCM) protocol.

Finite State Machine (FSM)

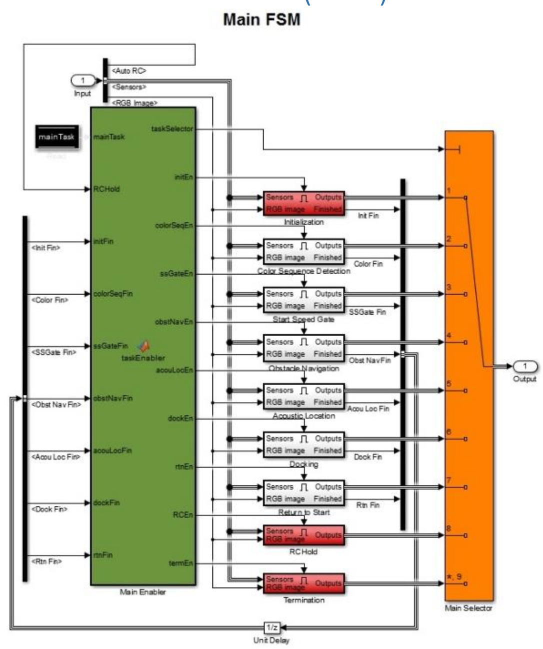

Figure 6: Structure of the Finite State Machine

In order to facilitate a logical and strategic approach to the competition as a whole, the Finite State Machine (FSM) structure is employed (Figure 6). This is done by organizing the tasks of the competition into different states which are enabled upon the completion of the previous state. This completion can be triggered by either a successful run, or a preset timeout in case of hardware or software malfunction. Furthermore, this structure also extends into the separate tasks where a lower level FSM governs the execution of subtasks and routines. This ultimately allows for a modular programming process where each action can be written and debugged on an individual basis.

Simultaneous Localization and Mapping (SLAM)

One major technical hurdle for SeaCat has been the vehicle's ability to retain some memory of its environment. Without an internal map of its surroundings, the vehicle can only be reactionary. That is to say, the vehicle control may only react to sensor measurements (e.g. video, LIDAR) at the current time.

To provide higher level functionality to the system, the vehicle must be able to leverage past sensor readings with current sensor data and form an estimate of important features in the robot's environment (Figure 3). With an internal map of the environment, the vehicle can perform tasks such as path planning and obstacle avoidance and will have more accurate vehicle pose estimates.

To provide SeaCat with this map, a Simultaneous Localization and Mapping (SLAM) algorithm was implemented. The particular variant of SLAM used in this implementation was FastSLAM, which aims to use a particle filter as a basis to solve the SLAM problem. SLAM works to combine sensor measurements and control inputs to form an estimate about the robot's pose as well as features within its environment. For the purpose of SeaCat, these features will be considered as buoys in the water.

Color Recognition with Bayesian Filtering

In outdoor applications, lighting conditions are constantly varying. From one minute to the next they can change from bright to cloudy. This can dramatically change the way the color of an object is perceived by a vision system.

Conventional methods typically use a heuristic approach to color detection, which can fail to detect important targets in difficult lighting conditions. To account for this, object detection and analysis has been done using the LIDAR image so a posterior analysis of color can be done.

The objects being analyzed by the proposed vision system have a known finite number of possible colors, and are tracked from frame to frame. A Bayesian Filter algorithm is used for recursive state estimation of the object's color, which determines what the most probable color of the object is.

The filter uses the mean color space values of the object detected and the previous color belief to determine the probable color. The mean values are compared to measured values from a training set for the filter, and the filter recursively refines the probability measured over several frames by updating the belief.

Template Matching for Symbol Recognition

Vision detection and analysis has always played a prominent role in RoboBoat tasks, however this is the first year where in addition to detection, the vessel must also be able to recognize a shape and use that information in its decision making.

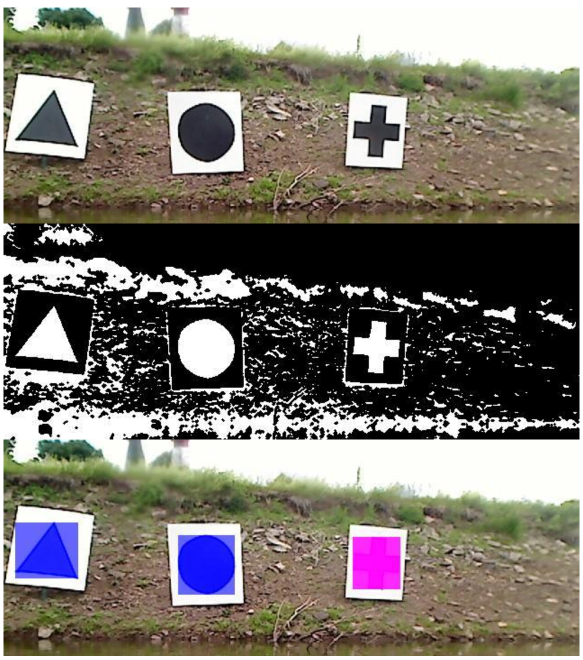

Figure 7: (Top) Original Video Frame, (Middle) Brightness Based Binary Mask, (Bottom) Template Detection with Cruciform Recognition

In order for SeaCat to perform symbol recognition, detection is first performed through the LIDAR/Video fusion where the area of interest in the video frame, i.e. the area around the signs, is found through depth mapping. The recognition phase then utilizes color thresholding in the HSV color space and image scaling in the area of interest to perform a pixel by pixel comparison between the captured video and low resolution templates of the symbols. After normalizing that similarity into the extent of the image, a decision can then be made as to the shape of the symbol.

CONCLUSION

This is a year of significant change for SeaCat in terms of improving its sensing and system robustness. SeaCat has logged countless hours of laboratory and in-water testing in order to assure that the newly implemented systems function properly by themselves and are integrated seamlessly as a whole. After much hard work, SeaCat is ready to compete in the 7th Annual AUVSI RoboBoat Competition. We are proud of what this team has accomplished and are confident going into the competition.

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